**Express Mail Label No.: EV 225206235 US**
**Date of Deposit: July 10, 2003**

**Attorney Docket No. 112675-128**

# MULTIPLE-CONTACT CABLE CONNECTOR ASSEMBLIES

## CROSS-REFERENCE TO RELATED APPLICATIONS

This patent application is a continuation-in-part of U.S. Patent Application Ser. No. 10/375,481, filed February, 27, 2003 which itself is a continuation-in-part of U.S. Patent Application Ser. No. 10/273,241, filed October 17, 2002, which claims priority to U.S. Provisional Patent Application Ser. No. 60/348,588 filed January 15, 2002.

## BACKGROUND

### Field of the Invention

The present invention is directed to electrical connectors, and in particular to woven electrical connectors.

### Discussion of Related Art

Components of electrical systems sometimes need to be interconnected using electrical connectors to provide an overall, functioning system. These components may vary in size and complexity, depending on the type of system. For example, referring to FIG. 1, a system may include a backplane assembly comprising a backplane or motherboard 30 and a plurality of daughter boards 32 that may be interconnected using a connector 34, which may include an array of many individual pin connections for different traces etc., on the boards. For example, in telecommunications applications where the connector connects a daughter board to a backplane, each connector may include as many as 2000 pins or more. Alternatively, the system may include components that may be connected using a single-pin coaxial or other type of connector, and many variations in-between. Regardless of the type of electrical system, advances in technology have led electronic circuits and components to become increasingly smaller and more powerful. However, individual connectors are still, in general, relatively large compared to the sizes of circuit traces and components.

Referring to FIGS. 2a and 2b, there are illustrated perspective views of the backplane assembly of FIG. 1. FIG. 2a also illustrates an enlarged section of the male portion of connector

34, including a housing 36 and a plurality of pins 38 mounted within the housing 36. FIG. 2b illustrates an enlarged section of the female portion of connector 34 including a housing 40 that defines a plurality of openings 42 adapted to receive the pins 38 of the male portion of the connector.

A portion of the connector 34 is shown in more detail in FIG. 3a. Each contact of the female portion of the connector includes a body portion 44 mounted within one of the openings (FIG. 2b, 42). A corresponding pin 38 of the male portion of the connector is adapted to mate with the body portion 44. Each pin 38 and body portion 44 includes a termination contact 48. As shown in FIG. 3b, the body portion 44 includes two cantilevered arms 46 adapted to provide an "interference fit" for the corresponding pin 38. In order to provide an acceptable electrical connection between the pin 38 and the body portion 44, the cantilevered arms 46 are constructed to provide a relatively high clamping force. Thus, a high normal force is required to mate the male portion of the connector with the female portion of the connector. This may be undesirable in many applications, as will be discussed in more detail below.

When the male portion of the conventional connector is engaged with the female portion, the pin 38 performs a "wiping" action as it slides between the cantilevered arms 46, requiring a high normal force to overcome the clamping force of the cantilevered arms and allow the pin 38 to be inserted into the body portion 44. There are three components of friction between the two sliding surfaces (the pin and the cantilevered arms) in contact, namely asperity interactions, adhesion and surface plowing. Surfaces, such as the pin 38 and cantilevered arms 46, that appear flat and smooth to the naked eye are actually uneven and rough under magnification. Asperity interactions result from interference between surface irregularities as the surfaces slide over each other. Asperity interactions are both a source of friction and a source of particle generation. Similarly, adhesion refers to local welding of microscopic contact points on the rough surfaces that results from high stress concentrations at these points. The breaking of these welds as the surfaces slide with respect to one another is a source of friction.

In addition, particles may become trapped between the contacting surfaces of the connector. For example, referring to FIG. 4a, there is illustrated an enlarged portion of the conventional connector of FIG. 3b, showing a particle 50 trapped between the pin 38 and cantilevered arm 46 of connector 34. The clamping force 52 exerted by the cantilevered arms must be sufficient to cause the particle to become partially embedded in one or both surfaces, as

shown in FIG. 4b, such that electrical contact may still be obtained between the pin 38 and the cantilevered arm 46. If the clamping force 52 is insufficient, the particle 50 may prevent an electrical connection from being formed between the pin 38 and the cantilevered arm 46, which results in failure of the connector 34. However, the higher the clamping force 52, the higher must be the normal force required to insert the pin 38 into the body portion 44 of the female portion of the connector 34. When the pin slides with respect to the arms, the particle cuts a groove in the surface(s). This phenomenon is known as "surface plowing" and is a third component of friction.

Referring to FIG. 5, there is illustrated an enlarged portion of a contact point between the pin 38 and one of the cantilevered arms 46, with a particle 50 trapped between them. When the pin slides with respect to the cantilevered arm, as indicated by arrow 54, the particle 50 plows a groove 56 into the surface 58 of the cantilevered arm and/or the surface 60 of the pin. The groove 56 causes wear of the connector, and may be particularly undesirable in gold-plated connectors where, because gold is a relatively soft metal, the particle may plow through the gold-plating, exposing the underlying substrate of the connector. This accelerates wear of the connector because the exposed connector substrate, which may be, for example, copper, can easily oxidize. Oxidation can lead to more wear of the connector due to the presence of oxidized particles, which are very abrasive. In addition, oxidation leads to degradation in the electrical contact over time, even if the connector is not removed and re-inserted.

One conventional solution to the problem of particles being trapped between surfaces is to provide one of the surface with "particle traps." Referring to FIGS. 6a-c, a first surface 62 moves with respect to a second surface 64 in a direction shown by arrow 66. When the surface 64 is not provided with particle traps, a process called agglomeration causes small particles 68 to combine as the surfaces move and form a large agglomerated particle 70, as illustrated in the sequence of FIGS. 6a-6c. This is undesirable, as a larger particle means that the clamping force required to break through the particle, or cause the particle to become embedded in one or both of the surfaces, so that an electrical connection can be established between surface 62 and surface 64 is very high. Therefore, the surface 64 may be provided with particle traps 72, as illustrated in FIGS. 6d-6g, which are small recesses in the surface as shown. When surface 62 moves over surface 64, the particle 68 is pushed into the particle trap 72, and is thus no longer available to cause plowing or to interfere with the electrical connection between surface 62 and

surface 64. However, a disadvantage of these conventional particle traps is that it is significantly more difficult to machine surface 64 with traps than without, which adds to the cost of the connector. The particle traps also produce features that are prone to increased stress and fracture, and thus the connector is more likely to suffer a catastrophic failure than if there were no particle traps present.

## SUMMARY OF THE INVENTION

According to one embodiment, a multiple-contact woven connector may comprise a weave arranged to provide a plurality of tensioned fibers and at least one conductor woven with the plurality of tensioned fibers so as to form a plurality of peaks and valleys along a length of the at least one conductor. The at least one conductor has a plurality of contact points positioned along the length of the at least one conductor, such that when the at least one conductor engages a conductor of a mating connector element, at least some of the plurality of contact points provide an electrical connection between the at least one conductor of the multiple-contact woven connector and the conductor of the mating connector element. The tensioned fibers of the weave provide a contact force between the at least some of the plurality of contact points of the at least one conductor of the multiple-contact woven connector and the conductor of the mating connector element.

According to another embodiment, an electrical connector comprises a first connector element comprising a weave including a plurality of non-conductive fibers and at least one conductor woven with the plurality of non-conductive fibers, the at least one conductor having a plurality of contact points along a length of the at least one conductor. The electrical connector further comprises a mating connector element that includes a rod member, wherein the first connector element and the mating connector element are adapted to engage such that at least some of the plurality of contact points of the first connector element contact the rod member of the mating connector element to provide an electrical connection between the first connector element and the mating connector element. The plurality of non-conductive fibers are tensioned so as to provide contact force between the at least some of the plurality of contact points of the first connector element contact the rod member of the mating connector.

In another embodiment, an electrical connector comprises a base member, first and second conductors mounted to the base member, and at least one elastomeric band that encircles the first and second conductors. The first and second conductors have an undulating form along

a length of the first and second conductors so as to include a plurality of contact points along the length of the first and second conductors.

An array of connector elements, according to one embodiment, comprises at least one power connector element and a plurality of signal connector elements. Each signal connector element comprises a weave including a plurality of non-conductive fibers and first and second conductors woven with the plurality of non-conductive fibers so as to form a plurality of peaks and valleys along a length of each of the first and second conductors, wherein the second conductor is located adjacent the first conductor, and a first one of the plurality of non-conductive fibers passes under a first peak of the first conductor and over a first valley of the second conductor. The first and second conductors have a plurality of contact points positioned along the length of the first and second conductors, the plurality of contact points adapted to provide an electrical connection between the first and second conductors of the signal connector element and a conductor of a mating signal connector element, and a contact force between the plurality of contact points of the first and second conductors of the signal connector element and the conductor of a mating signal connector element is provided by a tension of the weave.

According to yet another embodiment, an electrical connector comprises a housing including a base member and two opposing end walls, a plurality of nonconductive fibers mounted between the opposing end walls of the housing such that a predetermined tension is provided in the plurality of non-conductive fibers, and a first termination contact mounted to the base member and having a first plurality of conductors connected to a first end of the first termination contact, wherein the first plurality of conductors are woven with the plurality of non-conductive fibers to form a woven structure such that each conductor of plurality of conductors has a plurality of contact points along a length of each conductor.

Another embodiment includes an electrical connector array comprising a first housing element including a base portion and two opposing end walls, a plurality of nonconductive fibers mounted between the opposing end walls, a first conductor woven with the plurality of non-conductive fibers to provide a first electrical contact, a second conductor woven with the plurality of non-conductive fibers to provide a second electrical contact, and at least one insulating strand woven with the plurality of non-conductive fibers and positioned between the first and second conductors to electrically isolate the first electrical contact from the second electrical contact.

According to yet another embodiment, a multiple-contact woven connector comprises a weave including a plurality of tensioned, non-conductive fibers and first and second conductors woven with the plurality of tensioned, non-conductive fibers so as to form a plurality of peaks and valleys along a length of each of the first and second conductors. The second conductor is located adjacent the first conductor, and a first one of the plurality of tensioned non-conductive fibers passes under a first peak of the first conductor and over a first valley of the second conductor. The first and second conductors have a plurality of contact points positioned along the length of the first and second conductors, such that when the first and second conductors engage a conductor of a mating connector element, at least some of the plurality of contact points provide an electrical connection between the first and second conductors of the multiple-contact woven connector and the conductor of the mating connector element, wherein the plurality of tensioned, non-conductive fibers of the weave provide a contact force between the at least some of the plurality of contact points of the first and second conductors and the conductor of the mating connector element.

According to an alternative embodiment, a multi-contact woven connector comprises a plurality of loading fibers and at least one conductor having at least one contact point. The conductors are woven with at least a portion of the plurality of loading fibers and the plurality of loading fibers can thus deliver a contact force at each contact point of each conductor. In certain embodiments an electrical connection can be established between a first conductor and a second conductor. The conductors are preferably self-terminating. The multi-contact woven connector can further comprise a spring mount(s) having attachment points where ends of the loading fibers can be coupled to the attachment points. The multi-contact woven connector may also further comprise a floating end plate(s) having attachment points, where ends of the loading fibers can be coupled to the attachment points. Additionally, the multi-contact woven connectors can further comprise mating conductors having contact mating surfaces, where an electrical connection can be established between the contact point of the conductors and the contact mating surfaces of the mating conductors. In exemplary embodiments, the contact mating surfaces are curved and preferably convex where, for example, the contact mating surface can be defined by a constant radius of curvature.

According to another embodiment, the multi-contact woven connector can be a power connector comprised of a plurality of loading fibers, a power circuit having at least one

conductor and a return circuit also having at least one conductor. The conductors of the power and return circuits are woven with at least a portion of the plurality of loading fibers. The power connectors may further include mating conductors having a contact mating surface, where electrical connections can be established between the conductors of the power circuit and a first contact mating surface and between the conductors of the return circuit and a second contact mating surface.

According to a further embodiment, the multi-contact woven connector can be comprised of first and second sets of loading fibers and first and second sets of conductors. The conductors of the first set are woven with the first set of loading fibers to create a first weave having a first space, while the conductors of the second set are woven with the second set of loading fibers to create a second weave having a second space. In an exemplary embodiment, the weaves are arranged as woven tubes with the spaces disposed therein. The multi-contact woven connector may further include at least one tension spring for generating tensile loads within the loading fibers. The multi-contact woven connector may also further include first and second mating conductors that have contact mating surfaces. The mating conductors can be disposed with the spaces. In an exemplary embodiment, the mating conductors are substantially rod-shaped.

According to one embodiment, an electrical cable connector assembly includes a plurality of loading fibers and at least one conductor, wherein the at least one conductor has at least one contact point. A portion of the conductor(s) is woven with at least a portion of the plurality of loading fibers while another portion of the conductor(s) comprise a portion of a cable conductor. The loading fibers are designed to deliver a contact force at each contact point of the conductor(s).

According to another embodiment, an electrical cable connector assembly further includes a mating conductor having a contact mating surface, wherein an electrical connection can be established between the contact point(s) of the conductor(s) and the contact mating surface of the mating conductor.

In certain embodiments, an end portion of a conductor is woven with a first set of loading fibers to form a first weave and an opposite end portion of the conductor is woven with a second set of loading fibers to form a second weave. These embodiments may further include a first mating conductor having a contact mating surface a second mating conductor having a contact mating surface. An electrical connection can be established between a contact point located

along the end portion of the conductor and a contact mating surface of the first mating conductor and an electrical connection can also be established between a contact point located along the opposite end portion of the conductor and the contact mating surface of the second mating conductor.

In certain other embodiments, an electrical cable connector assembly only includes a single conductor with first portions of the conductor being woven with a first set of loading fibers to form a first weave and second portions of the conductor being woven with a second set of loading fibers to form a second weave. These embodiments may further include a first mating conductor having a contact mating surface and a second mating conductor that also has a contact mating surface. Electrical connection can be established between contact points located along the first portions of the conductor and the contact mating surface of the first mating conductor and electrical connections can also be established between contact points located along the second portions of the conductor and the contact mating surface of the second mating conductor.

According to further embodiment, an electrical cable connector assembly comprises a cable-to-cable connector assembly. In yet a further embodiment, an electrical cable connector assembly comprises a cable-to-board connector assembly.

According to another embodiment, an electrical cable connector assembly comprises a data cable connector assembly having at least one signal path.

According to a different embodiment, an electrical cable connector assembly comprises a power cable connector assembly.

## BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing and other features and advantages of the present invention will be apparent from the following non-limiting discussion of various embodiments and aspects thereof with reference to the accompanying drawings, in which like reference numerals refer to like elements throughout the different figures. The drawings are provided for the purposes of illustration and explanation, and are not intended to limit the breadth of the present disclosure.

FIG. 1 is a perspective view of a conventional backplane assembly;

FIG. 2a is a perspective view of a conventional backplane assembly showing an enlarged portion of a conventional male connector element;

FIG. 2b is a perspective view of a conventional backplane assembly showing an enlarged portion of a conventional female connector element;

FIG. 3a is a cross-sectional view of a conventional connector as may be used with the backplane assemblies of FIGS. 1, 2a, and 2b;

FIG. 3b is an enlarged cross-sectional view of a single connection of the conventional connector of FIG. 3a;

FIG. 4a is an illustration of an enlarged portion of the conventional connector of FIG. 3b, showing a trapped particle;

FIG. 4b is an illustration of the enlarged connector portion of FIG. 4a, with the particle embedded into a surface of the connector;

FIG. 5 is a diagrammatic representation of an example of the plowing phenomenon;

FIGS. 6a-g are diagrammatic representations of particle agglomeration, with and without particle traps present in a connector;

FIG. 7 is a perspective view of one embodiment of a woven connector according to aspects of the present disclosure;

FIG. 8 is a perspective view of an example of an enlarged portion of the woven connector of FIG. 7;

FIGS. 9a and 9b are enlarged cross-sectional views of a portion of the connector of FIG. 8;

FIG. 10 is a simplified cross-sectional view of the connector of FIG. 7 with movable, tensioning end walls;

FIG. 11 is a simplified cross-sectional view of the connector of FIG. 7 including spring members attaching the non-conductive weave fibers to the end walls;

FIG. 12 is a perspective view of another example of a tensioning mount;

FIG. 13a is an enlarged cross-sectional view of the woven connector of FIGS. 7 and 8;

FIG. 13b is an enlarged cross-sectional view of the woven connector of FIGS. 7 and 8 with a particle;

FIG. 14 is plan view of an enlarged portion of the woven connector of FIG. 7;

FIG. 15a is a perspective view of the connector of FIG. 7, mated with a mating connector element;

FIG. 15b is a perspective view of the connector of FIG. 7, mated with a mating connector element;

FIG. 16a is a perspective view of another embodiment of a connector according to aspects of the present disclosure;

FIG. 16b is a perspective view of the connector of FIG. 16 a with mating connector element disengaged;

FIG. 17a is a perspective view of another embodiment of a connector according to aspects of the present disclosure;

FIG. 17b is a perspective view of the connector of FIG. 17a;

FIG. 18 is a perspective view of another embodiment of a woven connector according to aspects of the present disclosure;

FIG. 19 is an enlarged cross-sectional view of a portion of the connector of FIG. 18;

FIG. 20a is a perspective view of an example of a mating connector element;

FIG. 20b is a cross-sectional view of another example of a the mating connector element;

FIG. 21 is a perspective view of another example of a mating connector element that may form part of the connector of FIG. 18;

FIG. 22 is a perspective view of another example of a mating connector element, including a shield, that may form part of the connector of FIG. 18;

FIG. 23 is a perspective view of an array of woven connectors according to aspects of present disclosure;

FIG. 24 is a cross-sectional view of an exemplary woven connector embodiment that illustrates the orientation of a conductor and a loading fiber;

FIGs. 25a-b illustrate conductor woven connector embodiments;

FIG. 26a-c illustrate woven connector embodiments having self-terminating conductors;

FIG. 27 illustrates the electrical resistance versus normal contact force relationship of several different woven connector embodiments;

FIGs. 28a and 28b are cross-sectional views of one woven connector embodiment in accordance with the teachings of the present disclosure;

FIG. 29 is an enlarged cross-sectional view of a woven connector embodiment having a convex contact mating surface;

FIG. 30 depicts an exemplary embodiment of a woven power connector in accordance with the teachings of the present disclosure;

FIG. 31 is rear view of the woven connector embodiment of FIG. 30;

FIG. 32 depicts several exemplary spring arm embodiments:

FIG. 33 illustrates the engagement of the conductors and mating conductors of the woven connector embodiment of FIG. 30;

FIG. 34 depicts another exemplary embodiment of a woven power connector in accordance with the teachings of the present disclosure;

FIG. 35 depicts another view of the connector of FIG. 34;

FIG. 36 depicts the woven connector embodiment of FIG. 34 having spring arms that generate a load within the loading fibers;

FIGs. 37a and 37b depict an exemplary embodiment of a woven data connector in accordance with the teachings of the present disclosure;

FIG. 38 depicts a traditional cable connector assembly;

FIG. 39 depicts an exemplary cable connector assembly in accordance with the teachings of the present disclosure; and

FIG. 40 depicts another exemplary cable connector assembly in accordance with the teachings of the present disclosure.

## DETAILED DESCRIPTION

The present invention provides an electrical connector that may overcome the disadvantages of prior art connectors. The invention comprises an electrical connector capable of very high density and using only a relatively low normal force to engage a connector element with a mating connector element. It is to be understood that the invention is not limited in its application to the details of construction and the arrangement of components set forth in the following description or illustrated in the drawings. Other embodiments and manners of carrying out the invention are possible. Also, it is to be understood that the phraseology and terminology used herein is for the purpose of description and should not be regarded as limiting. The use of "including," "comprising," or "having" and variations thereof is meant to encompass the items listed thereafter and equivalents thereof as well as additional items. In addition, it is to be appreciated that the term "connector" as used herein refers to each of a plug and jack connector element and to a combination of a plug and jack connector element, as well as respective mating connector elements of any type of connector and the combination thereof. It is also to be

appreciated that the term "conductor" refers to any electrically conducting element, such as, but not limited to, wires, conductive fibers, metal strips, metal or other conducting cores, etc.

Referring to FIG. 7, there is illustrated one embodiment of a connector according to aspects of the invention. The connector 80 includes a housing 82 that may include a base member 84 and two end walls 86. A plurality of non-conductive fibers 88 may be disposed between the two end walls 86. A plurality of conductors 90 may extend from the base member 84, substantially perpendicular to the plurality of non-conductive fibers 88. The plurality of conductors 90 may be woven with the plurality of non-conductive fibers so as to form a plurality of peaks and valleys along a length of each of the plurality of conductors, thereby forming a woven connector structure. Resulting from the weave, each conductor may have a plurality of contact points positioned along the length of each of the plurality of conductors, as will be discussed in more detail below.

In one embodiment, a number of conductors 90a, for example, four conductors, may together form one electrical contact. However, it is to be appreciated that each conductor may alone form a separate electrical contact, or that any number of conductors may be combined to form a single electrical contact. The connector of FIG. 7 may be include termination contacts 91 which may be permanently or removably connected to, for example, a backplane or daughter board. In the illustrated example, the termination contacts 91 are mounted to a plate 102 that may be mounted to the base member 84 of housing 82. Alternatively, the termination may be connected directly to the base member 84 of the housing 82. The base member 84 and/or end walls 86 may also be used to secure the connector 80 to the backplane or daughter board. The connector of FIG. 7 may be adapted to engage with one or more mating connector elements, as discussed below.

FIG. 8 illustrates an example of an enlarged portion of the connector 80, illustrating one electrical contact comprising the four conductors 90a. The four conductors 90a may be connected to a common termination contact 91. It is to be appreciated that the termination contact 91 need not have the shape illustrated, but may have any suitable configuration for termination to, for example, a semiconductor device, a circuit board, a cable, etc. According to one example, the plurality of conductors 90a may include a first conductor 90b and a second conductor 90c located adjacent the first conductor 90b. The first and second conductors may be woven with the plurality of nonconductive fibers 88 such that a first one of the non-conductive

fibers 88 passes over a valley 92 of the first conductor 90b and under a peak 94 of the second conductor 90c. Thus, the plurality of contact points along the length of the conductors may be provided by either the valleys or the peaks, depending on where a contacting mating connector is located. A mating contact 96, illustrated in FIG. 8, may form part of a mating connector element 97 that may be engaged with the connector 80, as illustrated in FIG. 15b. As shown in FIG. 8, at least some of the valleys of the conductors 90a provide the plurality of contact points between the conductors 90a and the mating contact 96. It is also to be appreciated that the mating contact need not have the shape illustrated, but may have any suitable configuration for termination to, for example, a semiconductor device, a circuit board, a cable, etc.

According to one embodiment, tension in the weave of the connector 80 may provide a contact force between the conductors of the connector 80 and the mating connector 96. In one example, the plurality of non-conductive fibers 88 may comprise an elastic material. The elastic tension that may be generated in the non-conductive fibers 88 by stretching the elastic fibers, may be used to provide the contact force between the connector 80 and the mating contact 96. The elastic non-conductive fibers may be prestretched to provide the elastic force, or may be mounted to tensioning mounts, as will be discussed in more detail below.

Referring to FIG. 9a, there is illustrated an enlarged cross-sectional view of the connector of FIG. 8, taken along line A-A in FIG. 8. The elastic non-conductive fiber 88 may be tensioned in the directions of arrows 93a and 93b, to provide a predetermined tension in the non-conductive fiber, which in turn may provide a predetermined contact force between the conductors 90 and the mating contact 96. In the example illustrated in FIG. 9a, the non-conductive fiber 88 may be tensioned such that the non-conductive fiber 88 makes an angle 95 with respect to a plane 99 of the mating conductor 96, so as to press the conductors 90 against the mating contact 96. In this embodiment, more than one conductor 90 may be making contact with the mating conductor 96. Alternatively, as illustrated in FIG. 9b, a single conductor 90 may be in contact with any single mating conductor 96, providing the electrical contact as discussed above. Similar to the previous example, the non-conductive fiber 86 is tensioned in the directions of the arrows 93a and 93b, and makes an angle 97 with respect to the plane of the mating contact 96, on either side of the conductor 90.

As discussed above, the elastic non-conductive fibers 88 may be attached to tensioning mounts. For example, the end walls 86 of the housing may act as tensioning mounts to provide a

tension in the non-conductive fibers 88. This may be accomplished, for example, by constructing the end walls 86 to be movable between a first, or rest position 250 and a second, or tensioned, position 252, as illustrated in FIG 10. Movement of the end walls 86 from the rest position 250 to the tensioned position 252 causes the elastic non-conductive fibers 88 to be stretched, and thus tensioned. As illustrated, the length of the non-conductive fibers 88 may be altered between a first length 251 of the fibers when the tensioning mounts are in the rest position 250, (when no mating connector is engaged with the connector 80), and a second length 253 when the tensioning mounts are in the tensioned position 252 (when a mating connector is engaged with the connector 80). This stretching and tensioning of the non-conductive fibers 88 may in turn provide contact force between the conductive weave (not illustrated in FIG. 10 for clarity), and the mating contact, when the mating connector is engaged with the connector element.

According to another example, illustrated in FIG. 11, springs 254 may be provided connected to one or both ends of the non-conductive fibers 88 and to a corresponding one or both of the end walls 86, the springs providing the elastic force. In this example, the non-conductive fibers 88 may be non-elastic, and may include an inelastic material such as, for example, a polyamid fiber, a polyaramid fiber, and the like. The tension in the non-conductive weave may be provided by the spring strength of the springs 254, the tension in turn providing contact force between the conductive weave (not illustrated for clarity) and conductors of a mating connector element. In yet another example, the non-conductive fibers 88 may be elastic or inelastic, and may be mounted to tensioning plates 256 (see FIG. 12), which may in turn be mounted to the end walls 86, or may be the end walls 86. The tensioning plates may comprise a plurality of spring members 262, each spring member defining an opening 260, and each spring member 262 being separated from adjacent spring members by a slot 264. Each non-conductive fiber may be threaded through a corresponding opening 260 in the tensioning plate 256, and may be mounted to the tensioning plate, for example, glued to the tensioning plate, or tied such that an end portion of the non-conductive fiber can not be unthreaded though the opening 260. The slots 264 may enable each spring member 262 to act independent of adjacent spring members, while allowing a plurality of spring members to be mounted on a common tensioning mount 256. Each spring member 262 may allow a small amount of motion, which may provide tension in the non-

conductive weave. In one example, the tensioning mount 256 may have an arcuate structure, as illustrated in FIG. 12.

According to one aspect of the invention, providing a plurality of discrete contact points along the length of the connector and mating connector may have several advantages over the single continuous contact of conventional connectors (as illustrated in FIGS. 3a, 3b and 4). For example, when a particle becomes trapped between the surfaces of a conventional connector, as shown in FIG. 4, the particle can prevent an electrical connection from being made between the surfaces, and can cause plowing which may accelerate wear of the connector. The applicants have discovered that plowing by trapped particles is a significant source of wear of conventional connectors. The problem of plowing, and resulting lack of a good electrical connection being formed, may be overcome by the woven connectors of the present invention. The woven connectors have the feature of being "locally compliant," which herein shall be understood to mean that the connectors have the ability to conform to a presence of small particles, without affecting the electrical connection being made between surfaces of the connector. Referring to FIGS. 13a and 13b, there are illustrated enlarged cross-sectional views of the connector of FIGS. 7 and 8, showing the plurality of conductors 90a providing a plurality of discrete contact points along the length of the mating connector element 96. When no particle is present, each peak/valley of conductors 90a may contact the mating contact 96, as shown in FIG. 13a. When a particle 98 becomes trapped between the connector surfaces, the peak/valley 100 where the particle is located, conforms to the presence of the particle, and can be deflected by the particle and not make contact with the mating contact 96, as shown in FIG. 13b. However, the other peaks/valleys of the conductors 90a remain in contact with the mating contact 96, thereby providing an electrical connection between the conductors and the mating contact 96. With this arrangement, very little force may be applied to the particle, and thus when the woven surface of the connector moves with respect to the other surface, the particle does not plow a groove in the other surface, but rather, each contact point of the woven connector may be deflected as it encounters a particle. Thus, the woven connectors may prevent plowing from occurring, thereby reducing wear of the connectors and extending the useful life of the connectors.

Referring again to FIG. 7, the connector 80 may further comprise one or more insulating fibers 104 that may be woven with the plurality of non-conductive fibers 88 and may be positioned between sets of conductors that together form an electrical contact. The insulating

fibers 104 may serve to electrically isolate one electrical contact from another, preventing the conductors of one electrical contact from coming into contact with the conductors of the other electrical contact and causing an electrical short between the contacts. An enlarged portion of an example of connector 80 is illustrated in FIG. 14. As shown, the connector 80 may include a first plurality of conductors 110a and a second plurality of conductors 110b, separated by one or more insulating fibers 104a and woven with the plurality of non-conductive fibers 88. As discussed above, the first plurality of conductors 110a may be connected to a first termination contact 112a, forming a first electrical contact. Similarly, the second plurality of conductors 110b may be connected to a second termination contact 112b, forming a second electrical contact. In one example, the termination contacts 112a and 112b may together form a differential signal pair of contacts. Alternatively, each termination contact may form a single, separate electrical signal contact. According to another example, the connector 80 may further comprise an electrical shield member 106, that may be positioned, as shown in FIG. 7, to separate differential signal pair contacts from one another. Of course, it is to be appreciated that an electrical shield member may also be included in examples of the connector 80 that do not have differential signal pair contacts.

FIGS. 15a and 15b illustrate the connector 80 in combination with a mating connector 97. The mating connector 97 may include one or more mating contacts 96 (see FIG. 8), and may also include a mating housing 116 that may have top and bottom plate members 118a and 118b, separated by a spacer 120. The mating contacts 96 maybe mounted to the top and/or bottom plate members 118a and 118b, such that when the connector 80 is engaged with the mating connector 97, at least some of the contact points of the plurality of conductors 90 contact the mating contacts 96, providing an electrical connection between the connector 80 and mating connector 97. In one example, the mating contacts 96 may be alternately spaced along the top and bottom plate members 118a and 118b as illustrated in FIG. 15a. The spacer 120 may be constructed such that a height of the spacer 120 is substantially equal to or slightly less than a height of the end walls 86 of connector 80, so as to provide an interference fit between the connector 80 and the mating connector 97 and so as to provide contact force between the mating conductors and the contact points of the plurality of conductors 90. In one example, the spacer may be constructed to accommodate movable tensioning end walls 86 of the connector 80, as described above.

It is to be appreciated that the conductors and non-conductive and insulating fibers making up the weave may be extremely thin, for example having diameters in a range of approximately 0.0001 inches to approximately 0.020 inches, and thus a very high density connector may be possible using the woven structure. Because the woven conductors are locally compliant, as discussed above, little energy may be expended in overcoming friction, and thus the connector may require only a relatively low normal force to engage a connector with a mating connector element. This may also increase the useful life of the connector as there is a lower possibility of breakage or bending of the conductors occurring when the connector element is engaged with the mating connector element. Pockets or spaces present in the weave as a natural consequence of weaving the conductors and insulating fibers with the non-conductive fibers may also act as particle traps. Unlike conventional particle traps, these particle traps may be present in the weave without any special manufacturing considerations, and do not provide stress features, as do conventional particle traps.

Referring to FIGS. 16a and 16b, there is illustrated another embodiment of a woven connector according to aspects of the invention. In this embodiment, a connector 130 may include a first connector element 132 and a mating connector element 134. The first connector element may comprise first and second conductors 136a and 136b that may be mounted to an insulating housing block 138. It is to be appreciated that although in the illustrated example the first connector element includes two conductors, the invention is not so limited and the first connector element may include more than two conductors. The first and second conductors may have an undulating form along a length of the first and second conductors, as illustrated, so as to include a plurality of contact points 139 along the length of the conductors. In one example of this embodiment, the weave is provided by a plurality of elastic bands 140 that encircle the first and second conductors 136a and 136b. According to this example, a first elastic band may pass under a first peak of the first conductor 136a and over a first valley of the second conductor 136b, so as to provide a woven structure having similar advantages and properties to that described with respect to the connector 80 (FIGS. 7-15b) above. The elastic bands 140 may include an elastomer, or may be formed of another insulating material. It is also to be appreciated that the bands 140 need not be elastic, and may include an inelastic material. The first and second conductors of the first connector element may be terminated in corresponding

first and second termination contacts 146, which may be permanently or removably connected to, for example, a backplane, a circuit board, a semiconductor device, a cable, etc.

As discussed above, the connector 130 may further comprise a mating connector element (rod member) 134, which may comprise third and fourth conductors 142a, 142b separated by an insulating member 144. When the mating connector element 134 is engaged with the first connector element 132, at least some of the contact points 139 of the first and second conductors may contact the third and fourth conductors, and provide an electrical connection between the first connector element and the mating connector element. Contact force may be provided by the tension in the elastic bands 140. It is to be appreciated that the mating connector element 134 may include additional conductors adapted to contact any additional conductors of the first connector element, and is not limited to having two conductors as illustrated. The mating connector element 134 may similarly include termination contacts 148 that may be permanently or removably connected to, for example, a backplane, a circuit board, a semiconductor device, a cable, etc.

An example of another woven connector according to aspects of the invention is illustrated in FIGS. 17a and 17b. In this embodiment, a connector 150 may include a first connector element 152 and a mating connector element 154. The first connector element 152 may comprise a housing 156 that may include a base member 158 and two opposing end walls 160. The first connector element may include a plurality of conductors 162 that may be mounted to the base member and may have an undulating form along a length of the conductors, similar to the conductors 136a and 136b of connector 130 described above. The undulating form of the conductors may provide a plurality of contact points along the length of the conductors. A plurality of non-conductive fibers 164 may be disposed between the two opposing end walls 160 and woven with the plurality of conductors 162, forming a woven connector structure. The mating connector element 154 may include a plurality of conductors 168 mounted to an insulating block 166. When the mating connector element 154 is engaged with the first connector element 152, as illustrated in FIG. 17b, at least some of the plurality of contact points along the lengths of the plurality of conductors of the first connector element may contact the conductors of the mating connector element to provide an electrical connection therebetween. In one example, the plurality of non-conductive fibers 164 may be elastic and may provide a contact force between the conductors of the first connector element and the mating connector

element, as described above with reference to FIGS. 9a and 9b. Furthermore, the connector 150 may include any of the other tensioning structures described above with reference to FIGS. 10a-12. This connector 150 may also have the advantages described above with respect to other embodiments of woven connectors. In particular, connector 150 may prevent trapped particles from plowing the surfaces of the conductors in the same manner described in reference to FIG. 13.

Referring to FIG. 18, there is illustrated yet another embodiment of a woven connector according to the invention. The connector 170 may include a woven structure including a plurality of non-conductive fibers (bands) 172 and at least one conductor 174 woven with the plurality of non-conductive fibers 172. In one example, the connector may include a plurality of conductors 174, some of which may be separated from one another by one or more insulating fibers 176. The one or more conductors 174 may be woven with the plurality of non-conductive fibers 172 so as to form a plurality of peaks and valleys along a length of the conductors, thereby providing a plurality of contact points along the length of the conductors. The woven structure may be in the form of a tube, as illustrated, with one end of the weave connected to a housing member 178. However, it is to be appreciated that the woven structure is not limited to tubes, and may have any shape as desired. The housing member 178 may include a termination contact 180 that may be permanently or removably connected to, for example, a circuit board, backplane, semiconductor device, cable, etc. It is to be appreciated that the termination contact 180 need not be round as illustrated, but may have any shape suitable for connection to devices in the application in which the connector is to be used.

The connector 170 may further include a mating connector element (rod member) 182 to be engaged with the woven tube. The mating connector element 182 may have a circular cross-section, as illustrated, but it is to be appreciated that the mating connector element need not be round, and may have another shape as desired. The mating connector element 182 may comprise one or more conductors 184 that may be spaced apart circumferentially along the mating connector element 182 and may extend along a length of the mating connector element 182. When the mating connector element 182 is inserted into the woven tube, the conductors 174 of the weave may come into contact with the conductors 184 of the mating connector element 182, thereby providing an electrical connection between the conductors of the weave and the mating connector element. According to one example, the mating connector element 182 and/or the

woven tune may include registration features (not illustrated) so as to align the mating connector element 182 with the woven tube upon insertion.

In one example, the non-conductive fibers 172 may be elastic and may have a circumference substantially equal to or slightly smaller than a circumference of the mating connector element 182 so as to provide an interference fit between the mating connector element and the woven tube. Referring to FIG. 19, there is illustrated an enlarged cross-sectional view of a portion of the connector 170, illustrating that the nonconductive fibers 172 may be tensioned in directions of arrows 258. The tensioned nonconductive fibers 172 may provide contact force that causes at least some of the plurality of contact points along the length of the conductors 174 of the weave to contact the conductors 184 of the mating connector element. In another example, the non-conductive fibers 172 may be inelastic and may include spring members (not shown), such that the spring members allow the circumference of the tube to expand when the mating connector element 182 is inserted. The spring members may thus provide the elastic/tension force in the woven tube which in turn may provide contact force between at least some of the plurality of contact points and the conductors 184 of the mating connector element 182.

As discussed above, the weave is locally compliant, and may also include spaces or pockets between weave fibers that may act as particle traps. Furthermore, one or more conductors 174 of the weave may be grouped together (in the illustrated example of FIGS. 18 and 19, the conductors 174 are grouped in pairs) to provide a single electrical contact. Grouping the conductors may further improve the reliability of the connector by providing more contact points per electrical contact, thereby decreasing the overall contact resistance and also providing capability for complying with several particles without affecting the electrical connection.

Referring to FIGS. 20a and 20b, there are illustrated in perspective view and cross-section, respectively, two examples of a mating connector element 182 that may be used with the connector 170. According to one example, illustrated in FIG. 20a, the mating connector element 182 may include a dielectric or other non-conducting core 188 surrounded, or at least partially surrounded, by a conductive layer 190. The conductors 184 may be separated from the conductive layer 190 by insulating members 192. The insulating members may be separate for each conductor 184 as illustrated, or may comprise an insulating layer at least partially

surrounding the conductive layer 190. The mating connector element may further include an insulating housing block 186.

According to another example, illustrated in FIG. 20b, a mating connector element 182 may comprise a conductive core 194 that may define a cavity 196 therein. Any one or more of an optical fiber, a strength member to increase the overall strength and durability of the rod member, and a heat transfer member that may serve to dissipate heat built up in the connector from the electrical signals propagating in the conductors, may be located within the cavity 196. In one example, a drain wire may be located within the cavity and may be connected to the conductive core to serve as a grounding wire for the connector. As illustrated in FIG. 20a, the housing block 186 may be round, increasing the circumference of the mating connector element, and may include one or more notches 198 that may serve as registration points for the connector to assist in aligning the mating connector element with the conductors of the woven tube. Alternatively, the housing block may include flattened portions 200, as illustrated in FIG. 20b, that may serve as registration guides. It is further to be appreciated that the housing block may have another shape, as desired and may include any form of registration known to, or developed by, one of skill in the art.

FIG. 21 illustrates yet another example of a mating connector element 182 that may be used with the connector 170. In this example, the mating connector element may include a dielectric or other non-conducting core 202 that may be formed with one or more grooves, to allow the conductors 184 to be formed therein, such that a top surface of the conductors 184 is substantially flush with an outer surface of the mating connector element.

According to another example, illustrated in FIG. 22, the connector 170 may further comprise an electrical shield 204 that may be placed substantially surrounding the woven tube. The shield may comprise an non-conducting inner layer 206 that may prevent the conductors 174 from contacting the shield and thus being shorted together. In one example, the rod member may comprise a drain wire located within a cavity of the mating connector element, as discussed above, and the drain wire may be electrically connected to the electrical shield 204. The shield 204 may comprise, for example, a foil, a metallic braid, or another type of shield construction known to those of skill in the art.

Referring to FIG. 23, there is illustrated an example of an array of woven connectors according to aspects of the invention. According to one embodiment, the array 210 may

comprise one or more woven connectors 212 of a first type, and one or more woven connectors 214 of a second type. In one example, the woven connectors 212 may be the connector 80 described above in reference to FIGS. 7-15b, and may be used to connect signal traces and or components on different circuit boards to one another. The woven connectors 214 may be the connector 170 described above in reference to FIGS. 18-22, and may be used to connector power traces or components on the different circuit boards to one another. In one example where the connector 170 may be used to provide power supply connections, the rod member 180 may be substantially completely conductive. Furthermore, in this example, there may be no need to include insulating fibers 176, and the fibers 172, previously described as being non-conductive, may in fact be conductive so as to provide a larger electrical path between the woven tube and the rod member. The connectors may be mounted to a board 216, as illustrated, which may be, for example, a backplane, a circuit board, etc., which may include electrical traces and components mounted to a reverse side, or positioned between the connectors (not shown).

As discussed herein, the utilization of conductors being woven or intertwined with loading fibers, e.g., non-conductive fibers, can provide particular advantages for electrical connector systems. Designers are constantly struggling to develop (1) smaller electrical connectors and (2) electrical connectors which have minimal electrical resistance. The woven connectors described herein can provide advantages in both of these areas. The total electrical resistance of an assembled electrical connector is generally a function of the electrical resistance properties of the male-side of the connector, the electrical resistance properties of the female-side of the connector, and the electrical resistance of the interface that lies between these two sides of the connector. The electrical resistance properties of both the male and female-sides of the electrical connector are generally dependent upon the physical geometries and material properties of their respective electrical conductors. The electrical resistance of a male-side connector, for example, is typically a function of its conductor's (or conductors') cross-sectional area, length and material properties. The physical geometries and material selections of these conductors are often dictated by the load capabilities of the electrical connector, size constraints, structural and environmental considerations, and manufacturing capabilities.

Another critical parameter of an electrical connector is to achieve a low and stable separable electrical resistance interface, i.e., electrical contact resistance. The electrical contact resistance between a conductor and a mating conductor in certain loading regions can be a

function of the normal contact force that is being exerted between the two conductive surfaces. As can be seen in FIG. 24, the normal contact force 310 of a woven connector is a function of the tension T exerted by the loading fiber 304, the angle 312 that is formed between the loading fiber 304 and the contact mating surface 308 of the mating conductor 306, and the number of conductors 302 of which the tension T is acting upon. As the tension T and/or angle 312 increase, the normal contact force 310 also increases. Moreover, for a desired normal contact force 310 there may be a wide variety of tension T/angle 312 combinations that can produce the desired normal contact force 310.

FIGs. 25a-b illustrate a method for terminating the conductors 302 that are woven onto loading fibers 304. Referring to FIG. 25a, conductor 302 winds around a first loading fiber 304a, a second loading fiber 304b and a last loading fiber 304z. The orientation and/or pattern of the conductor 302 – loading fiber 304 weave can vary in other embodiments, e.g., a valley formed by a conductor 302 may encompass more than one loading fiber 304, etc. The conductors 302 on one side terminate at a termination point 340. Termination point 340 will generally comprise a termination contact, as previously discussed. In an exemplary embodiment, the conductors 302 may also terminate on the opposite side of the weave at another termination point (not shown) that, unlike termination point 340, will generally not comprise a termination contact. FIG. 25b illustrates a preferred embodiment for weaving the conductors 302 onto the loading fibers 304a-z. In FIG. 25b, the conductor 302 is woven around the first and second loading fibers 304a, 304b in the same manner as discussed above. In this preferred embodiment, however, conductor 302 then wraps around the last loading fiber 304z and is then woven around the second loading fiber 304b and then the first loading fiber 304a. Thus, the conductor 302 begins at termination point 340, is woven around the conductors 304a, 304b, wrapped around loading fiber 304z, woven (again) around loading fibers 304b, 304a, and terminates at termination point 340. Having a conductor 302 wrap around the last loading fiber 304z and becoming the next conductor (thread) in the weave eliminates the need for a second termination point. Consequently, when a conductor 302 is wrapped around the last loading fiber 304z in this manner the conductor 302 is referred to as being self-terminating.

FIGs. 26a-c illustrate some exemplary embodiments of how conductor(s) 302 can be woven onto loading fibers 304. The conductor 302 of FIGs 26a-c is self-terminating and, while only one conductor 302 is shown, persons skilled in the art will readily appreciate that additional

conductors 302 will usually be present within the depicted embodiments. FIG. 26a illustrates a conductor 302 that is arranged as a straight weave. The conductor 302 forms a first set of peaks 364 and valleys 366, wraps back upon itself (i.e., is self-terminated) and then forms a second set of peaks 364 and valleys 366 that lie adjacent to and are offset from the first set of peaks 364 and valleys 366. A peak 364 from the first set and a valley 366 from the second set (or, alternatively, a valley 366 from the first set and a peak 364 from the second set) together can form a loop 362. Loading fibers 304 can be located within (i.e., be engaged with) the loops 362. While the conductor 302 of FIGs. 26a-c is shown as being self-terminating, in other exemplary embodiments, the conductors 302 need not be self-terminating. Using non self-terminating conductors 302, to form a straight weave similar to the one disclosed in FIG. 26a, a first conductor 302 forms a first set of peaks 364 and valleys 366 while a second conductor 302 forms a second set of peaks 364 and valleys 366 which lie adjacent to and are offset from the first set. The loops 362 are similarly formed from corresponding peaks 364 and valleys 366. FIG. 26b illustrates a conductor 302 that is arranged as a crossed weave. The conductor 302 of FIG. 26b forms a first set of peaks 364 and valleys 366, wraps back upon itself and then forms a second set of peaks 364 and valleys 366 which are interwoven with, and are offset from, the first set of peaks 364 and valleys 366. Similarly, peaks 364 from the first set and valleys 366 from the second set (or, alternatively, valleys 366 from the first set and peaks 364 from the second set) together can form loops 362, which may be occupied by loading fibers 304. Non self-terminating conductors 302 may also be arranged as a crossed weave.

FIG. 26c depicts a self-terminating conductor 302 that is cross woven onto four loading fibers 304. The conductor 302 of FIG. 26c forms five loops 362a-e. In certain exemplary embodiments, a loading fiber(s) 304 is located within each of the loops 362 that are formed by the conductors 302. However, not all loops 362 need to be occupied by a loading fiber 304. FIG. 26c, for example, illustrates an exemplary embodiment where loop 362c does not contain a loading fiber 304. It may be desirable to include unoccupied loops 362 within certain conductor 302 – loading fiber 304 weave embodiments so as to achieve a desired overall weave stiffness (and flexibility). Having unoccupied loops 362 within the weave may also provide improved operations and manufacturing benefits. When the weave structure is mounted to a base, for example, there may be a slight misalignment of the weave relative to the mating conductor. This misalignment may be compensated for due to the presence of the unoccupied loop 362. Thus, by

utilizing loops that are unoccupied or "unstitched", i.e., a loading fiber 304 does not contact the loop, compliance of the weave structure to ensure better conductor/mating conductor conductivity while keeping the weave tension to a minimum may be achieved. Utilizing unoccupied loops 362 may also permit greater tolerance allowances during the assembly process. Moreover, the use of unstitched loops 362 may allow the use of common tooling for different connector embodiments (e.g., the same tooling might be used for a weave 8 having eight loops 362 with six "stitched" loading fibers 304 as for a weave having eight loops 362 with eight loading fibers 304. As an alternative to using an unstitched loop 362, a straight (unwoven) conductor 302 may be used instead.

Tests of a wide variety of conductor 302 - loading fiber 304 weave geometries were performed to determine the relationship between normal contact force 310 and electrical contact resistance. Referring to FIG. 27, the total electrical resistance of the tested woven connector embodiments, as represented on y-axis 314, of the different woven connector embodiments (as listed in the legend) was determined over a range of normal contact forces, as represented on x-axis 316. As represented in FIG. 27, the general trend 318 indicates that as the normal contact force (in Newtons (N)) increases, the contact resistance component of the total electrical resistance (in milli-ohms (mOhms)) generally decreases. Persons skilled in the art will readily recognize, however, that the decrease in contact resistance only extends over a certain range of normal contact forces; any further increases over a threshold normal contact force will produce no further reduction in electrical contact resistance. In other words, trend 318 tends to flatten out as one moves further and further along the x-axis 316.

From the data of FIG. 27, for example, one can then determine a normal contact force (or range thereof) that is sufficient for minimizing a woven connector's electrical contact resistance. To generate these normal contact forces, the preferred operating range of the tension T to be loaded in the loading fiber(s) 304 and the angle 312 (which is indicative of the orientation of the loading fiber(s) 304 relative to the conductor(s) 302) can then be determined for an identified woven connector embodiment. As persons skilled in the art will readily appreciate, the vast majority of the conventional electrical connectors that are available today operate with normal contact forces ranging from about 0.35 to 0.5 N or higher. As is evident by the data represented in FIG. 27, by generating multiple contact points on conductors 302 of a woven connector system, very light loading levels (i.e., normal contact forces) can be used to produce very low

and repeatable electrical contact resistances. The data of FIG. 27, for example, demonstrates that for many of the woven connector embodiments tested, normal contact forces of between approximately 0.020 and 0.045 N may be sufficient for minimizing electrical contact resistance. Such normal contact forces thus represent an order of magnitude reduction in the normal contact forces of conventional electrical connectors.

Recognizing that very low normal contact forces can be utilized in these woven multi-contact connectors, the challenge then becomes how to generate these normal contact forces reliably at each of the conductor 302's contact points. The contact points of a conductor 302 are the locations where electrical conductivity is to be established between the conductor 302 and a contact mating surface 308 of a mating conductor 306. FIGs. 28a and 28b depict an exemplary embodiment of a woven multi-contact connector 400 that is capable of generating desired normal contact forces at each of the contact points. FIGs. 26a and 26b depict cross-sectional views of a woven connector 400 having a woven connector element 410 and a mating connector element 420. The woven connector element 410 is comprised of loading fiber(s) 304 and conductors 302. The ends of the loading fibers(s) 304 generally are secured to end plates (not shown) or other fixed structures, as further described below. The loading fiber(s) 304 may be in an unloaded (non-tensioned) or loaded condition prior to the woven connector element 410 being engaged with the mating connector element 420. While only one loading fiber 304 is shown in these cross-sectional views, it should be recognized that additional loading fibers 304 are preferably located behind (or in front of) the depicted loading fiber 304. Woven connector element 410 has three bundles, or arrays, of conductors 302 woven around each loading fiber 304. The hidden-line portions of conductors 302 reflect where the woven conductors' 302 peaks and valleys are out of plane with the particular cross-section shown. Generally, a second loading fiber 304 (not shown) would be utilized in conjunction with these out-of-plane peaks and valleys. Although not shown here, conductors 302 can be placed directly against adjacent conductors 302 so that electrical conductivity between adjacent conductors 302 can be established.

FIG. 28b depicts the woven connector element 410 of FIG. 28a after being engaged with the mating connector element 420. To engage the woven connector element 410, the woven connector element 410 is inserted into cavity 422 of mating connector element 420. In certain embodiments, a front face (not shown) of the mating conductors 306 may be chamfered to better accommodate the insertion of the woven connector element 410. Upon insertion into the mating

connector element 420, the loading fibers 304 are displaced to accommodate the profile of the cavity 422 and the presence of the mating conductors 306. In some embodiments, the displacement of the loading fibers 304 can be facilitated through a stretching of the loading fibers 304. In other embodiments, this displacement can be accommodated through the tightening of an otherwise slack (in a pre-engaged condition) loading fiber 304 or, alternatively, a combination of stretching and tightening, which results in a tension T being present in the loading fibers 304. As previously discussed, due to the orientation and arrangement of the loading fibers 304 - conductors 302 weave, the tension T in the loading fibers 304 will cause certain normal contact forces to be present at the contact points. As can be seen in FIG. 28b, the woven connector 400 has mating conductors 306 that are alternately located on the interior surfaces (which define the cavity 422) of the mating connector element 420. This alternating contact arrangement produces alternating contacts on opposite parallel planar contact mating surfaces 308.

Instead of utilizing a flat (e.g., substantially planar) contact mating surface 308 as depicted in FIG. 28b, another embodiment uses a curved, e.g., convex, contact mating surface 308. The curvature of the contact mating surface 308 may permit improved tolerance controls for contact between the contact points of the conductors 302 and the mating conductors 306 in the normal direction. The curved surface (of the contact mating surfaces 308) helps maintain a very tightly controlled normal force between these two separable contact surfaces. The curved surface itself, however, does not generally assist in maintaining lateral alignment between the conductors 302 and the mating conductors 306. Insulating fibers (e.g., insulating fibers 104 as shown in FIG. 7) placed parallel with and interspersed between segments of conductors 302 could be utilized to assist with the lateral alignment of adjacent conductors 302. The curvature of the contact mating surface 308 need not be that significant; improved location tolerances can be realized with a relatively small amount of curvature. In some preferred embodiments, contact mating surfaces 308 having a large radius of curvature may be used to achieve some desired manufacturing location tolerances. FIG. 29 illustrates an alternative mating conductor 306 having a curved contact mating surface 308 that could be used in the woven connector 400 of FIG. 28. The curvature of the contact mating surface 308 allows for a very generous positioning tolerance during manufacturing and operation.

Referring to FIG. 29, improved location tolerances can often be achieved by utilizing contact mating surfaces 308 which have a radius of curvature *R* 336 that is greater than the width *W* 309 of the mating conductor 306. Specifically, the relationship between the lateral spacing *L* 332 found between two conductors 302 and the angle $\alpha$ 334 between the two conductors 302 and the radius of curvature *R* 336 of the contact mating surface 308 is given by the formula $L \approx \alpha R$. The minimum of the lateral spacing *L* 332 is set by the diameter of the conductors 302 and, thus, the lateral spacing *L* 332 may be tightly controlled by locating the conductors 302 directly against each other. In other words, in certain exemplary embodiments the conductors 302 are located so that no gap exists between the adjacent conductors 302. Thus, for a very low angle $\alpha$ 334, the required radius of curvature *R* 336 can then be determined. In an exemplary embodiment having an angle $\alpha$ 334 of 0.25 degrees and conductors 302 having a diameter of 0.005 inches, for example, a preferred contact mating surface's 308 radius of curvature *R* 336 would thus be on the order of about 2.29 inches. The tolerance on this is also quite generous as the angle $\alpha$ 334 is directly related to the radius of curvature *R* 336. For example, if the tolerance on the radius of curvature *R* 336 was set at ±0.10 inches, then the angle $\alpha$ 334 could vary from between 0.261 degrees and 0.239 degrees. To illustrate the benefits of using a curved contact mating surface 308, to maintain a tolerance of 0.03 degrees on the flat array embodiment of FIG. 28 would require a tolerance of 0.0000105 inches on the offset height *H* 324. Additionally, the introduction of curved contact mating surfaces 308 does not materially affect the overall height of the woven connectors. With a radius of curvature *R* 336 of 2.29 inches and a mating conductor 306 width *W* 309 of 0.50 inches, for example, the total height 311 of the arc would only be about 0.014 inches, i.e., the contact mating surface 308 is nearly flat.

Load balancing is an issue with multi-contact electrical connectors, and particularly so with multi-contact electrical power connectors. Load imbalances within electrical connectors can cause the connectors to burn-out and thus become inoperable. In their basic form, electrical connectors simply provide points of electrical contact between male and female conductive pins. In electrical connectors that are load balanced, the incoming currents are evenly distributed through each of the contact points. Thus for a 10 amp connector having four contact points, the connector is balanced if 2.5 amps are delivered through each contact point. If a connector is not load balanced, then more current will pass through one contact than another contact. This imbalance of electrical current may cause overloading at one of the "overloaded" contact points,

which can result in localized welding, localized thermal spikes and conductor plating damage, all of which can lead to increased connector wear and/or very rapid system failure. A load imbalance can be caused by having different conductive path lengths in the connector system, high separable interface electrical contact resistance at one point (e.g., due to poor contact geometry), or large thermal gradients in the connector. An advantage of power connectors as taught by this disclosure is that they can be fully (or substantially) load balanced across many contact points. For each conductor 302 (i.e., conductive fiber), the first contact point that is to make electrical contact with the mating conductor 306 can be designed to carry the full current load that is to be allocated for that conductor 302. Subsequent contact points located along the conductor 302 are also generally designed to carry the full current load in case there is a failure (to provide electrical contact) at the first contact point. The additional contact points located downstream of the first contact point on each of the conductors 302 therefore can carry all or some of the allocated current, but their primary purpose is typically to provide contact redundancy. Moreover, as already stated, the multiple contact points help to prevent localized hot spots by producing multiple thermal pathways.

In most exemplary embodiments, the conductors 302 of a connector will generally have similar geometries, electrical properties and electrical path lengths. In some embodiments, however, the conductors 302 of a connector may have dissimilar geometries, electrical properties and/or electrical path lengths. Additionally, in some preferred power connector embodiments, each conductor 302 of a connector is in electrical contact with the adjacent conductor(s) 302. Providing multiple contact points along each conductor 302 and establishing electrical contact between adjacent conductors 302 further ensures that the multi-contact woven power connector embodiments are sufficiently load balanced. Moreover, the geometry and design of the woven connector prohibit a single point interface failure. If the conductors 302 located adjacent to a first conductor 302 are in electrical contact with mating conductors 306, then the first conductor 302 will not cause a failure (despite the fact that the contact points of the first conductor 302 may not be in contact with a mating conductor 306) since the load in the first conductor 302 can be delivered to a mating conductor 306 via the adjacent conductors 302.

FIG. 30 illustrates an exemplary embodiment of a load-balanced multi-contact woven power connector 500. The power connector 500 consists of two extended arrays, a power array and a return array. These arrays provide multiple contact points over a wide area, which can

result in high redundancy, lower separable electrical contact resistance, and better thermal dissipation of parasitic electrical losses. The power connector 500 as shown is a 30 amp DC connector having a power circuit 512 and a return (ground) circuit 514. Persons skilled in the art will readily recognize that other power connectors having different arrangements and power capabilities can be constructed without departing from the scope of the present disclosure. The load capabilities of the power connector 500 can be increased by adding additional conductors 302, for example. Referring to FIG. 30, the power connector 500 is comprised of a woven connector element 510 and a mating connector element 520. The mating connector element 520's external housing has been omitted from these figures for clarity. The woven connector element 510 includes a housing 530, a power circuit 512, a return circuit 514, end plates 536, alignment pins 534 and a plurality of loading fibers 304. The housing 530 has several recesses 532 that can facilitate the mating of the mating connector element's external housing (not shown) to the housing 530 of the woven connector element 510. The recesses 532 may accommodate an alignment pin (not shown) or a fastening means (not shown). The power circuit 512 is comprised of several conductors 302 woven around several loading fibers 304 in accordance with the teachings of the present disclosure. To achieve a desired load capacity of 30 amps, the power circuit 512 may have between 20-40 conductors 302 depending upon the diameter of the conductors 302 and their electrical properties, for example.

In certain exemplary embodiments, the conductors 302 can be comprised of copper or copper alloy (e.g., C110 copper, C172 Beryllium Copper alloy) wires having diameters between 0.0002 and 0.010 inches or more. Alternatively, the conductors may also be comprised of copper or copper alloy flat ribbon wires having comparable rectangular cross-section dimensions. The conductors 302 may also be plated to prevent or minimize oxidation, e.g., nickel plated or gold plated. Acceptable conductors 302 for a given woven connector embodiment should be identified based upon the desired load capabilities of the intended connector, the mechanical strength of the candidate conductor 302, the manufacturing issues that might arise if the candidate conductor 302 is used and other system requirements, e.g., the desired tension T. The conductors 302 of the power circuit 512 exit a back portion of the housing 530 and may be coupled to a termination contact or other conductor element through which power can be delivered to the power connector 500. As is discussed in more detail below, the loading fibers 304 of the power circuit 512 are capable of carrying a tension T that ultimately

translates into a contact normal force being asserted at the contact points of the conductors 302. In exemplary embodiments, the loading fibers 304 may be comprised of nylon, fluorocarbon, polyaramids and paraaramids (e.g., Kevlar®, Spectra®, Vectran®), polyamids, conductive metals and natural fibers, such as cotton, for example. In most exemplary embodiments, the loading fibers 304 have diameters (or widths) of about 0.010 to 0.002 inches. However, in certain embodiments, the diameter/widths of the loading fibers 304 may be as low as 18 microns when high performance engineered fibers (e.g., Kevlar) are used. In a preferred embodiment, the loading fibers 304 are comprised of a non-conducting material. The return circuit 514 is arranged in the same manner as the power circuit 512, except that the power circuit 512 is coupled to a termination contact that can be connected to a return circuit.

The mating connector element 520 of the power connector 500 consists of an external housing (not shown), an insulating housing 526, two mating conductors 522 and two spring arms 528. The mating conductors 522 are attached to opposite sides of the insulating housing 526 so that when the mating connector element 520 is engaged with the woven connector element 510, the contact points of the conductors 302 (of circuits 512 and 514) will come into electrical contact with the mating conductors 522. Insulating housing 526 serves to provide a structural foundation for the mating conductors 522 and also to electrically isolate the mating conductors 522 from each other. Insulating housing 526 has holes 523 that can accommodate the alignment pins 534 and thus assist in facilitating the coupling of the mating connector element 520 to the woven connector element 510 (or vice versa). Spring arms 528 may act to firmly secure the mating connector element 520 to the woven connector element 510. Additionally, in certain preferred embodiments, spring arms 528 also operate in conjunction with the end plates 536 of the woven connector element 510 to exert a tension load T in the loading fibers 304 of the woven connector element 510.

FIG. 31 illustrates an exemplary embodiment of a woven connector element 510 having floating end plates 536 that are capable of generating a tension T in loading fibers 304. FIG. 31 depicts a rear view of the woven connector element 510 of FIG. 30 with a back portion of the housing 530 removed for clarity. Loading fibers 304 are interwoven with the conductors 302 of the power circuit 512 and the return circuit 514. The ends of the loading fibers 304 are coupled to the two opposite floating end plates 536. The ends of the loading fibers 304 can be coupled to the floating end plates through a wide variety means know in the art, for example, by mechanical

fastening means or bonding means. The floating end plates 536 may be allowed to float (i.e., remain unconstrained) prior to the installation of mating connector element 520 or, in an alternate embodiment, secondary spring mechanisms (not shown) coupled to the housing 530 and an end plate 536 may be used to control the lateral (e.g., outward) displacement of the end plates 536, i.e., in a direction away from the circuits 512, 514. In some exemplary embodiments, the loading fibers 304 will be in an un-tensioned state prior to the installation of the mating connector element 520. In other exemplary embodiments, however, some tensile load (which will usually be less than the tension T needed to generate a desired normal contact force) may be present in the loading fibers 304 prior to the installation of the mating connector 520. This pre-installation tensile load may be due to the presence of the secondary spring mechanisms or, alternatively, may be pre-loaded onto the loading fibers 304 when the loading fibers 304 are coupled to the end plates 536.

Upon inserting the mating connector element 520 into the woven connector element 510 (or vice versa), the spring arms 528 of the mating connector element 520 engage the floating end plates 536 of the woven connector element 510. Based upon the stiffness of the spring arms 528, the stiffness and/or elasticity of the conductors 302, the stiffness of the secondary spring mechanism (if present) and the pre-installation dimensions/locations of the spring arms 528 and the end plates 536, the end plates 536 will become displaced (move outward) to some degree because of the presence of the spring arms 528. The spring arms 528, of course, may also experience some deflection during this process. This outward displacement of the floating end plates 536 can cause a tension T to be generated in the loading fibers 304. In an exemplary embodiment, the loading fibers 304 are comprised of an elastic material. In such exemplary embodiments, the relative displacement of the two end plates 536 may result in a substantially equal amount of stretching in the load fibers 304. In other exemplary embodiments, spring arms 528 can be mounted directly on the floating end plates 536 of the woven connector element 510 instead of on the mating connector element 520 as depicted in FIG. 30.

FIGs. 32a-c illustrates some exemplary embodiments of spring arms 528 that are constructed in accordance with the teachings of the present disclosure. The effective spring height 529 of the spring arms 528 can be increased by embedding a portion of the spring arm 528 within the insulating housing 526 of the mating connector element 520. It is desirable that the spring arms 528 be capable of generating a large relative deflection motion (e.g., approximately

0.020 inches) for a given load when the mating connector element 520 is inserted into the woven connector element 510. By generating a large relative motion, the manufacturing and alignment tolerances on the assembly can be loosened (e.g., the loading fiber's 304 length tolerance could be modified from ± 0.005 inches to ± 0.015 inches) while still keeping the final assembled line tolerance within a specified range. FIG. 32a depicts an exemplary embodiment of spring arms 528 where little or none of the spring arm 528 is embedded into the insulating housing 526 of the mating connector element 520. FIGs. 32b-c illustrate two preferred embodiments of spring arms 528 that have a significant portion of the spring arms 528 embedded into the insulating housing 526 of the mating connector element 520. The portion of the spring arms 528 that are embedded in the insulating housing 526 should be free to move (within the insulating housing 526) except at the anchors 525, where they are fixed. The spring arms 528 of FIG. 32b essentially travel around half a circle and terminate at anchors 525, which are substantially parallel to the effective direction of tip deflection 527. The spring arms 528 of FIG. 32c essentially travel around three-quarters of a circle and terminate at anchors 525 which are substantially orthogonal to the effective direction of tip deflection 527. The spring arm 528 embodiments depicted in FIGs. 32b-c will have longer effective spring heights 529, which yield correspondingly larger tip deflection motions 527 for the same force as compared to the "short" spring arms 528 embodiment of FIG. 32a.

In certain exemplary embodiments, the spring arm 528 can be comprised of a metal or metal alloy, such as nitinol, for example, and can be a wire spring or a ribbon spring, amongst others. Depending on the diameter of the spring arm 528 and connector 500 dimensions, multiple turns of the spring arm 528 may also be possible.

FIG. 33 is a front view of the power connector 500 after the mating connector element 520 has been engaged with the woven connector element 510. The external housing and the spring arms 528 of the mating connector element 520 and the housing 530 of the woven connector element 510, amongst other features, have been removed for clarity. As can be seen in FIG. 33, after the engagement of the mating connector element 520, the contact points of the conductors 302 of the circuits 512, 514 are in electrical contact with the contact mating surface 524 of the mating connector 522. As previously discussed, while the contact mating surface 524 can be substantially planar, in a preferred embodiment the contact mating surface 524 is defined by some radius of curvature *R* (not shown), e.g., *R* 336. In some preferred embodiments, this

radius of curvature $R$ 336 will be greater than the mating conductor's 522 width $W$ (not shown), e.g., $W$ 309.

FIG. 34 illustrates another exemplary embodiment of a multi-contact woven power connector 600 that is highly balanced. The power connector 600 consists of two extended arrays, a power array 612 and a return array 614. These arrays provide multiple contact points over a wide area, which can result in high redundancy, lower separable electrical contact resistance, and better thermal dissipation of parasitic electrical losses. The power connector 600 could be a 30 amp DC connector. The power connector 600 is comprised of a woven connector element 610 and a mating connector element 620. The woven connector element 610 is comprised of a housing 630, a power circuit 612, a return circuit 614, two spring mounts 634, a guide member 636 and several loading fibers 304. The housing 630 has several holes 632 which can accommodate the alignment pins 642 of the mating connector element 620. The power circuit 612 is comprised of several conductors 302 woven around several loading fibers 304 in accordance with the teachings of the present disclosure. In a preferred embodiment, these conductors 302 are arranged to be self-terminating. The conductors 302 of the power circuit 612 exit a back portion of the housing 630 and may form a termination point where power can be delivered to the power connector 600. As is discussed in more detail below, the loading fibers 304 of the power circuit 612 (and return circuit 614) are capable of carrying a tension T that ultimately translates into a contact normal force being asserted at the contact points of the conductors 302. The return circuit 614.is arranged in the same manner as the power circuit 612. The loading fibers 304 of the power connector 600 are comprised of a non-conducting material, which may or may not be elastic. The guide member 636 is mounted to an inside wall of the housing 630 and is positioned so as to provide structural support for the loading fibers 304 and, indirectly, the power circuit 612 and return circuit 614. The ends of the loading fibers 304 are secured to the spring mounts 634. As is described in greater detail below, the spring mounts 634 are capable of generating a tensile load T in the attached loading fibers 304 of the woven connector element 610.

The mating connector element 620 of the power connector 600 consists of a housing 640, two mating conductors 622 and alignment pins 642. The mating conductors 622 are secured to an inside wall of the housing 640 such that when the mating connector element 620 is engaged with the woven connector element 610, the contact points of the conductors 302 (of circuits 612

and 614) will come into electrical contact with the mating conductors 622. Alignment pins 642 are aligned with the holes 632 of the woven connector element 610 and thus assist in facilitating the coupling of the mating connector element 620 to the woven connector element 610 (or vice versa).

Power connector 600 has several of the same features of the power connector 500, but uses a different mechanism for producing the tension T (and, thus, the normal contact force) in the conductor 302 – loading fiber 304 weave. Rather than using the floating end plates 536 of power connector 500, power connector 600 uses pre-tensioned spring mounts 634 to generate and maintain the required normal contact force between the contact points of the conductors 302 (of the circuits 612, 614) and the mating conductors 622. FIG. 35 depicts the power connector 600 after the mating connector element 620 has been engaged with the woven connector element 610. After engagement, the contact points of the conductors 302 of both the power circuit 612 and return circuit 614 are in electrical contact with the contact mating surfaces 624 of the mating conductors 622.

In a preferred embodiment, the contact mating surfaces 624 are convex surfaces that are defined by a radius of curvature $R$. As shown in FIG. 35, the convex contact mating surfaces 624 are located on a bottom side of the mating conductors 622, i.e., after engagement, the conductors 302 are located below the mating conductors 622. In an exemplary embodiment, the guide member 636 is positioned such that the upper potion of the guide member 636 is located above the contact mating surfaces 624. After engagement, the loading fibers 304 run from an end 638 of the first spring mount 634, against the convex contact mating surface 624 that corresponds to the power circuit 612, over the top portion of the guide member 636, against the convex contact mating surface 624 that corresponds to the return circuit 612 and then terminates at an end 639 of the second spring mount 634. In other exemplary embodiments, the contact mating surfaces 624 can be located on the top-side of the mating conductors 622, and the loading fibers 304 would therefore extend over these top-located convex contact mating surfaces 624. The locations of the end 638, guide member 636, contact mating surfaces 624 and end 639, working in conjunction with the tension T generated in the loading fibers 304, facilitate the delivery of the contact normal forces at the contact points of the conductors 302.

FIGs. 36a-c depicts an exemplary embodiment of a pair of spring mounts 634 that could be used in power connector 600. The loading fibers 304 have been omitted for clarity but it

should be understood that the ends of the loading fibers 304 are to be attached to the ends 638, 639. Prior to engagement, the loading fibers 304 are supported by a support pin (not shown), such as the guide member 636, for example. During engagement, the loading fibers 304 are aligned with contact mating surfaces 624. FIGs. 36a-c illustrate how the spring mounts 638 function in the power connector 600. FIG. 36a illustrates the spring mounts 634 in an un-loaded state that occurs prior to the loading fibers being coupled to the ends 638, 639. Referring to FIG. 36b, to attach the loading fibers 304 to the ends 638, 639, the ends 638, 639 are slightly moved inward and the loading fibers 304 are then anchored to the ends 638, 639. Persons skilled in the art will readily recognize a wide variety of ways in which the loading fibers 304 can be anchored to the ends 638, 639, e.g., using slots, anchor points, fasteners, clamps, welding, brazing, bonding, etc. After the loading fibers 304 have been anchored to the ends 638, 639 of the spring mounts 634, a small tension force will generally be present in the loading fibers 304. Referring now to FIG. 36c, during the insertion of the mating connector element 620 into the woven connector element 610, the loading fibers 304 are pushed under the contact mating surfaces 624 (or, alternatively, pulled over the contact mating surfaces 624, if the surfaces 624 are located on the top side of the mating conductors 622) and the mating of the power connector 600 is then completed. To facilitate the engagement of the loading fibers 304 with the contact mating surfaces 624, the ends 638, 639 of the spring mounts 634 will generally undergo some additional deflection. Thus, the loading fibers 304 will be subjected to an additional tensile load so that a resultant tension T is then present in the loading fibers 304 (and, consequently, contact normal forces are present at the contact points of the conductors 302).

The electrical connectors constructed in accordance with the teachings of the present disclosure are inherently redundant. If any of the loading fibers 304 of these embodiments breaks or looses tension, the remaining loading fibers 304 could be able to continue to assert sufficient tension T so that electrical contact at the contact points of the conductors 302 could be maintained and, thus, the connectors could continue to carry the rated current capacity. In certain exemplary embodiments, a complete failure of all the loading fibers 304 would have to occur for the connector to loose electrical contact. In the case of dirt or a contaminant in the system, the multiple contact points are much more efficient at maintaining contact than a traditional one or two contact point connector. If a single point failure does occur (due to dirt or mechanical failure), then there are generally at least three surrounding local contact points which

would be capable of handling the diverted current: the next contact point found in line (or previous in line) on the same conductor 302, and since each conductor 302 is preferably in electrical contact with the conductors 302 that are adjacent to it, the current can also flow into these adjacent conductors 302 and then through the contact points of these conductors 302.

The teachings of the present disclosure, furthermore, can be utilized in many woven multi-contact data connector embodiments. In designing such woven multi-contact data connector embodiments, issues that are commonly considered by those skilled in the art when designing data connectors, such as impedance matching, rf shielding and cross-talk issues, amongst others, need to be taken into consideration. In data connector embodiments, a data signal path can be established through a conductor(s) of a woven connector element and a mating conductor of a mating connector element. The primary difference between the woven data and power connector embodiments is the size of the individual circuit. In woven power connector embodiments, the contact surfaces (i.e., the contact points of the conductors and corresponding contact mating surfaces) tend to be much larger than those of the woven data connector embodiments due to the higher current requirements. The woven data connector embodiments, moreover, are more likely to contain multiple isolated circuit (signal) paths mounted on a single conductor 302 – loading fibers 304 weave. This allows for a high density of signal paths in the woven data connector embodiments. Additionally, there is much more flexibility in the implementation of the data connector embodiments due to the different pin/ground/signal/power combinations that are possible in order to generate the required impedance, cross talk and signal skew characteristics.

The data connector embodiments of the present disclosure also provide advantages over traditional data connectors that use stamped spring arm contacts. First, it is easier to keep very tight tolerances at very small sizes with the woven data connectors than the traditional stamped spring arm contact methods. Second, drawn wire (e.g., for conductors 302) is available at low costs even at very small sizes, whereas comparable sized conventional stampings having similar tolerances can become quite expensive. Third, signal path stubs at the connector interfaces can be reduced or eliminated in the woven data connectors of the present disclosure. Stubs are present in a circuit when energy propagating through a part of the circuit has no place to go and tends to be reflected back within the circuit. At high frequencies, these interface stubs can produce jitter, signal distortion and attenuation, and the interaction of these stubs with other

signal discontinuities in the circuit can cause loss of data, degradation of speed and other problems. The very nature of conventional fork and blade-type connector produces a stub. The length of this stub will generally depend upon the tolerance stack up of the system (e.g., connector tolerance, backplane/daughter card flatness, stamping tolerance, board alignment tolerance, etc.) and the length of the stub may vary by an order of magnitude over a single connector. With the woven data connector embodiments of the present disclosure, there are almost no stubs within the circuits at any time, from full insertion to partial insertion, due to the presence of multiple contact points along a conductor 302. Lastly, the woven data connector embodiments may be more flexible for tuning trace impedances because, in addition to ground placement, the materials that comprise the conductor 302 – loading fibers 304 (and insulating fiber 104, if present) weave can be changed to obtain more flexible impedance characteristics without any major retooling of the process line.

FIGs. 37a-b illustrates an exemplary embodiment of a multi-contact woven data connector 700. The data connector 700 includes a woven connector element 710 and a mating connector element 720. The woven connector element 710, as seen in FIG. 37a, comprises a housing 714, three sets of loading fibers 304 (wherein each set has six loading fibers 304) and conductors 302 that are woven onto each set of loading fibers 304. In certain exemplary embodiments, the woven connector element 710 may further include ground shields 712 and alignment pins and/or holes for receiving alignment pins. In data connector embodiments, each signal path can be comprised of a single conductor 302 or, alternatively, many conductors 302. However, to achieve certain desired signal path electrical properties, e.g., capacitance, inductance and impedance characteristics, in most preferred embodiments each signal path will consist of between one and four conductors 302. The conductors 302 may be self-terminating. In certain further preferred embodiments, a signal path will consist of two self-terminating conductors 302. When more than one (self-terminating or non self-terminating) conductor 302 is used to form a signal path, the conductors 302 forming the signal path should preferably be in electrical contact with each other. The conductors 302 comprising a single signal path generally will form a termination which may be located on the backside of the housing 714. The woven connector element 710 has twelve separate signal paths, four signal paths being located on each of the three sets of loading fibers 304.

The woven connector element 710 further includes insulating fibers 104 that are woven onto the loading fibers 304 between the electrical signal paths (i.e., the conductors 302). The insulating fibers 104 serve to electrically isolate the signal paths from each other in a direction along the loading fibers 304. The woven connector element 710 of FIG. 37a only depicts three sets of insulating fibers 104, a single set of insulating fibers 104 being located on each set of loading fibers 304. The sets of insulating fibers 104 have been removed for clarity. In some exemplary embodiments, additional sets of insulating fibers 104 would also be present (i.e., woven) between the other signal paths located on each set of loading fibers 304. In some exemplary embodiments, the insulating fibers 104 may be self-terminating. Furthermore, in certain exemplary embodiments the woven connector element 710 may further comprise tensioning mechanisms (not shown), e.g., spring arms, floating plates, spring mounts, etc., located at or near the ends of the loading fibers 304. These tensioning mechanisms may be capable of generating desired tensile loads in the loading fibers 304, as previously discussed.

The mating connector element 720 of the data connector 700, as seen in FIG. 37b comprises a housing 730, ground shields 732 and three insulating housings 728. The grounding shields 732 can be deposed on the backside of the insulating housings 728, i.e., on a side opposite face 726. In certain exemplary embodiments, the mating connector element 720 may further include alignment pins and/or holes for receiving alignment pins. Each insulating housing 728 has four mating conductors 722 located on a face 726. The mating conductors 722 are arranged on the faces 726 so that when the woven connector element 710 engages the mating connector element 720 (or vice versa), electrical connections between the contact points of the conductors 302 and the mating conductors 722 can be established. Thus, the signal paths of the data connector 700 are established via the conductors 302 of the woven connector element 710 and their corresponding mating conductors 722 of the mating connector element 720. The mating conductor 722 generally will form a termination point, e.g., board termination pin, which may be located on the backside of the housing 730. In exemplary embodiments, the shape and orientation of the mating conductors 722, as situated on the face 726, closely matches the shape and orientation of the conductor(s) 302, by which an electrical connection is to be established. During engagement, the faces 726 of the insulating housings 728 engage the conductors 302 - loading fiber 304 weave of the woven connector element 710. In an exemplary embodiment, the faces 726 and/or the contact mating surfaces of the mating conductors 722 form a continuous

convex surface. In a preferred embodiment, this convex surface can be defined by a constant radius of curvature.

In the depicted exemplary embodiment, housing 730 forms slots 734 which can accommodate the sets of loading fibers 304 when the woven connector element 710 is engaged to the mating connector element 720. After engagement, the ground shields 712 of the woven connector element 710 can help to electrically shield the mating conductors 722 of the mating connector element 720, while the ground shields 732 of the mating connector element 720 similarly can help to electrically shield the conductors 302 of the woven connector element 710. The placement and design of ground shields 712, 732 can change the electrical properties (e.g., capacitance and inductance) of the signal traces and provide a means of shielding adjacent signal lines (or adjacent differential pairs) from cross talk and electromagnetic interference (EMI). By changing the capacitance and inductance of the signal traces at particular points or regions, the impedance of the signal path can be controlled. The higher the speed of the signal, the better control that is required for impedance matching and EMI shielding. The ground planes of the data connector 700 can be on the back face of the insulating housing 728 of the mating connector element 720 and in independent metal shields 712 of the woven connector element 710. Ground pins/planes must be a conductive material and are preferably, but not necessarily, solid. In preferred embodiments, each signal path is contained within a conductive ground shield (coaxial or twinaxial) structure. This can provide the optimum signal isolation with possibilities for reducing signal attenuation and distortion. The ground shields 712, 732 of the woven connector element 710 and mating connector element 720, respectively, may or may not be in contact with each other after engagement but, preferably, some continuous ground connection should be established between the two halves of the connector 700. This can be done by forcing the ground shields 712 and 732 to contact each other or, alternatively, using one or more data pins as a ground connection between the two halves.

The embodiments described above generally include conductors that terminate at termination contacts (or points). These connector embodiments can be utilized as power connectors, data connectors or as electrical switches. Moreover, these connector embodiments can generally be implemented as board-to-board connector assemblies, board-to-cable connector assemblies or cable-to-cable connector assemblies. In the cable-side of a conventional cable-type connector assembly, be it a board-to-cable connector assembly or a cable-to-cable connector

assembly, the termination contacts of the connector are coupled to conductors that are disposed within the cable-portion of the assembly. The termination contacts of the connector are coupled to the cable conductors via crimping, soldering, press-fitting an end of the cable conductors onto the termination contacts, or by other techniques. In general, one termination contact will be coupled to one cable conductor. The coupling of the connector termination contacts to the cable conductors can introduce electrical discontinuities or distortions which can have negative influences on the cable connector assembly's ability to serve as a high speed data transmission connector or a power connector. In data cable connector assemblies, each additional terminal or junction that is found within the electrical path is a potential source of signal distortion and discontinuity, which thus can degrade the integrity of the data signal. Similarly, in power cable connector assemblies, discontinuities or distortions within the electrical current can adversely impact low inductance designs and produce a system hot spot under high-current applications. The coupling of the termination contacts to the cable conductors can also have implications on the manufacturing costs and system reliability.

FIG. 38 illustrates one embodiment of a traditional cable connector assembly. The cable connector assembly 270 of FIG. 38 includes a connector subassembly 272 and a cable subassembly 278. The connector subassembly 272 includes a housing 274 and five conductive contacts 276. The conductive contacts 276 include termination contacts (not shown) which are located on the backside of the housing 274. The conductive contacts 276 of assembly 270 are two-bladed spring arm male contact pins which may be designed for contacting an edge of a circuit board or other similar contact shapes. Therefore, the cable connector assembly 270 can be used in board-to-cable connector applications. In other traditional connector assemblies, contacts 276 can be a single arm spring beam contact or, alternatively, the female part of a connector may be coupled to the cable subassembly 278.

The cable subassembly 278 includes an insulated sleeve 282 and five conductors 280. The conductors 280 are disposed within the insulated sleeve 282. The insulated sleeve serves to electrically isolate the conductors 280 from each other while maintaining the conductors 280 within a flexible, unitary structure. To provide continuous conductive paths across the cable connector assembly 270, the contact terminations of the connector subassembly 272 are coupled to, i.e., attached to, the conductors 280 of the cable subassembly 278. As previously discussed, the coupling of the contact terminations of the connector subassembly 272 to the conductors 280

of the cable subassembly 278 can adversely impact the performance capabilities of the cable connector assembly 270.

The multi-contact woven technology described herein can be utilized to provide cable connector assemblies where the conductors of the weave are also used as the conductors of the cable subassembly. Thus, in accordance with the teachings of the present disclosure, exemplary cable connector assemblies may utilize conductors that are integral to the connector subassembly and the cable subassembly, thereby eliminating the need to couple the conductors to the interface of the subassemblies. An exemplary embodiment of a cable connector assembly in accordance with the present disclosure is shown in FIG. 39. Cable connector assembly 800 of FIG. 39 includes a cable subassembly 810 and a woven connector element 820, i.e., a connector subassembly. Cable subassembly 810 includes an insulated sleeve 812 that encapsulates portions of five conductors 302. A portion of each conductor 302 extends throughout the cable subassembly 810 (i.e., a portion of each conductor 302 acts as a cable conductor), while end portions of each conductor 302 extend into the woven connector element 820 where they are woven onto loading fibers 304. Similar to traditional cable connectors, the insulated sleeve 812 of the cable subassembly 810 serves to electrically isolate the conductors 302 from each other while providing a cable subassembly 810 that has a flexible, unitary structure. The conductors 302 of cable connector assembly 800 can be comprised of a wide variety of configurations and compositions, e.g., solid wire, stranded wire, flat ribbon, spring alloy, pure copper alloy, etc.

In the exemplary embodiment of FIG. 39, woven connector element 820 includes four loading fibers 304 and a housing (not shown). As previously discussed herein, the woven connector element 820 may further include tensioning springs, spring mounts, end plates, etc., which can facilitate, generate and/or assist in providing the necessary tensile loads within the loading fibers 304.

In the exemplary embodiment shown in FIG. 39, an end portion of each conductor 302 is woven with the loading fibers 304 to form a weave. Insulators 822 may be disposed on the loading fibers 304 between adjacent conductors 302 so as electrically isolate the conductors 302 from each other. In a preferred embodiment, the conductors 302 are self-terminating and, thus, wrap back upon the loading fibers 304 in the area of the weave. The conductors 302, however, need not be terminated back within the insulated sleeve 812 of the cable subassembly 810. In certain exemplary embodiments, in the area of the weave, after wrapping back upon the loading

fibers 304, the end of a conductor 302 will terminate before the insulated sleeve 812 and be held in place by the weave/loading fibers 304. In certain further exemplary embodiments, an insulating material (not shown) may be disposed around the ends of the conductors 302. The insulating material may be arranged as a collar that secures the end of the conductor 302 to a portion of the same conductor 302 that lies next to its end.

Exemplary cable connector assembly 800, as shown, is configured as a flat-ribbon cable connector assembly. In other exemplary embodiments, cable connector assembly 800 can be configured as a round multi-conductor cable connector assembly or as a coaxial cable connector assembly, depending upon the type of conductor 302 that is utilized or how the conductors 302 are arranged within the cable subassembly 810, or both. In other words, in addition to flat cables, in other exemplary embodiments the woven connector element 820 can also be built onto the ends of a multi-conductor round cable subassembly 810 or coaxial cable subassembly 810. In each of these exemplary embodiments, the conductors 302 which form the weave(s) of the woven connector element 820 continue into cable subassembly 810 and, thus, constitute the conductors of the cable subassembly 810 as well.

In a preferred embodiment, cable connector assembly 800 is utilized as a data cable connector assembly where conductors 302 of the assembly 800 act as separate data paths. In other exemplary embodiments, cable connector assembly 800 may be utilized as a power cable connector assembly, which may have a power circuit, a return circuit, or both. For data cable connector assemblies, an advantage of the integral connector is that there is an absolute minimum number of interconnects within the cable connector assembly. In certain exemplary power cable connector assembly embodiments, the conductors 302 are maintained in electrical contact with each other, either within the weave of the woven connector element 820, or within the cable subassembly 810, or both. Providing electrical connections between the conductors 302 of a power cable connector assembly can provide significant advantages in regards to electrical conductivity, thermal management, system impedance and system inductance issues. In a preferred embodiment, the connector subassembly 810 of a power cable connector assembly consists of a flat cable arrangement where there is no isolation between successive conductors 302. A flat cable connector subassembly has a large surface area for convective cooling and, additionally, has a lower effective impedance. With new system development for low voltage/high current DC supplies for integrated circuits and memory applications, there is a

driving requirement for low inductance and evenly matched impedance power cables and, thus, many exemplary embodiments that are constructed in accordance with the teachings of the present disclosure may be well suited for such applications. In certain exemplary embodiments, multiple flat power cable connector assemblies can be stacked together, e.g., laminated together, to produce a mega power cable connector assembly that has very low inductance properties.

Cable connector assembly 800 is arranged in a generally straight termination form, meaning that the orientation of the cable subassembly 810 is substantially the same as the orientation of the woven connector element 820. In alternate embodiments, however, cable connector assembly 800 can be arranged with a wide variety of bend orientations. In an embodiment having a 90° bend, for example, the orientation of the cable subassembly 810 is substantially perpendicular to the orientation of the woven connector element 820. Other exemplary embodiments may be configured as 45° bends, 60° bends, 135° bends, etc., depending upon the applications in which a cable connector assembly is to be utilized.

The unwoven end of the conductors 302 of cable connector assembly 800 (of FIG. 39) will generally form a termination contact or termination contacts. For example, in power cable connector assemblies, the conductors 302 may form a single termination contact, two termination contacts - where one may be a contact for a power circuit and the other a contact for a return circuit - or, alternatively, several termination contacts. In a preferred embodiment of a data cable connector assembly, each conductor 302 forms a single termination contact, i.e., each conductor 302 represents a separate signal path. In certain exemplary embodiments, these end portions of the conductors 302 are woven onto a second set of loading fibers 304 (not shown). Thus, cable connector assembly 800 can include a second woven connector element 820 which is located at the other end of the cable subassembly 810. In other exemplary embodiments, these end portions of the conductors 302 can form, or be coupled to, mating conductors.

In a certain exemplary embodiment of a power cable connector assembly, the connector assembly includes a single conductor 302 which is drawn back and forth across the cable subassembly 810 and woven with two sets of loading fibers 304 that are located at each end of the cable subassembly 810. Thus, such an embodiment includes a woven connector element 820 located at each end of the cable subassembly 810. The portions of the conductor 302 which comprise the cable subassembly 810 can be coated or overmolded for insulation, thus creating an insulated sleeve 812, for example. The configuration of this exemplary power cable connector

assembly can provide a high effective density of conductive cross-section material for a given area.

In other certain exemplary embodiments, the conductor(s) 302 may only be woven on a single side of the loading fibers 304, e.g., the loading fibers 304 lie on top of the conductor(s) 302. With these types of weave configurations, the weave shape may be formed via a simple rolling or stamping die process without requiring any secondary fold back operations. While these configurations does not provide a weave where the conductors 302 completely capture and enclose the loading fibers 304, the housing of the woven connector element 820 can compensate for this by providing positive placement and retention of the loading fibers 304 and conductors 302 so as to provide the necessary normal forces at the contact points of the conductors 302.

FIG. 40 illustrates another exemplary embodiment of a cable connector assembly in accordance with the teachings of the present disclosure. Cable connector assembly 900 of FIG. 40 includes a cable subassembly 910, a woven connector element 920 and a mating connector element 940. Similar to cable connector 800, cable assembly 910 includes an insulated sleeve 912 that encapsulates portions of the conductors 302. Cable connector 900 includes three conductors 302. A portion of each conductor 302 extends throughout the cable subassembly 910, while end portions of each conductor 302 extends into the woven connector element 920 where they are woven onto loading fibers 304 to form a weave. Woven connector element 920 includes four loading fibers 304 and a housing 922. As previously discussed, the woven connector element 920 may further include tensioning springs, spring mounts, end plates, etc., which can facilitate, generate and/or assist in providing the necessary tensile loads within the loading fibers 304. The loading fibers 304 may be pre-tensioned during the assembly process or may become tensioned when the mating connector element 940 is engaged with the woven connector element 920.

Mating conductor 940 includes a housing 944 and three mating conductors 942. Housing 944 may be comprised of a non-conducting material. When the mating conductor 940 is engaged with the woven connector element 920, due to the normal forces generated by the loading fibers 304, the contact points of the conductors 302 (in the area of the weave) come into electrical contact with the corresponding mating conductors 942. In most exemplary embodiments, the mating contact surfaces of the mating conductors 942 are curved surfaces as previously discussed herein. Additionally, the housing 944 itself may have an upper curved

surface which can assist in providing the necessary engagement with the conductors 302 and loading fibers 304 of the woven connector element 920. When engaged, the conductors 302 of the woven connector element 920 may become displaced to some degree, e.g., the weave may become bowed. In certain embodiments the cable subassembly 910 is flexible. In such embodiments, the displacement of the conductors 302 within the woven connector element 920 can be compensated by the flexure of the cable subassembly 910. In many exemplary cable connector embodiments, however, the conductors 302 are arranged in a curved manner (as viewed in the cross-section) within the housing 922 of the woven connector element 920 and/or the cable subassembly 910 so that the conductors 302 undergo a relatively smooth transition from the cable subassembly 910 to the woven connector element 920 when the woven connector element 920 is engaged with a mating conductor 942. Providing too much deformation of the conductors 302 during engagement/disengagement can lead to premature failure of the conductors 302 due to fatigue.

Cable connector assembly 900 can be implemented as a data cable connector assembly or a power connector assembly. Moreover, cable connector assembly 900 (as well as cable connector assembly 800) can be implemented as a cable-to-cable connector or, alternatively, as a cable-to-board connector, where the woven connector element 920 is constructed onto and as a part of the cable connector assembly itself.

Having thus described various illustrative embodiments and aspects thereof, modifications and alterations may be apparent to those of skill in the art. Such modifications and alterations are intended to be included in this disclosure, which is for the purpose of illustration only, and is not intended to be limiting. The scope of the invention should be determined from proper construction of the appended claims, and their equivalents.